TMO TECHNOLOGY DEVELOPMENT PLAN

Work Area Name: Radio Metric Tracking

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OBJECTIVE:
Develop new technologies to enable fully autonomous navigation and spacecraft operations. Reduce operational costs and improve accuracy of radio metric tracking techniques used for trajectory determination and science applications..

GOALS and SIGNIFICANCE:
GPS-Derivative Navigation (GDN) is a new technology thrust to develop and demonstrate autonomous spacecraft tracking and communications systems for deep space missions. GDN is a technology spinoff from GPS-based tracking techniques, but GDN can be applied in deep space far beyond the range of the GPS constellation. Areas of application include autonomous in situ multimission navigation for Mars missions, and the New Millennium Program. The significance of the GDN technology is that it can lower NASA tracking operations costs by an order of magnitude or more. It will also be possible to combine telemetry and navigation, and some command and control functions into one GDN sensor, such as the Autonomous Formation Flyer (AFF). This consolidation of spacecraft subsystems should reduce spacecraft complexity and cost.

Global Wide Area Differential GPS (WADGPS) enables low-cost, autonomous onboard navigation of Earth orbiters, with potential for onboard generation of science products. These developments could result in significant cost savings for NASA mission operations, perhaps into the millions of dollars per year, depending on the number of Earth orbiter missions supported. The system can accomodate an unlimited number of low-Earth orbiter or near-Earth users.

The transfer of the highly automated prototype GPS calibration system frees up 1000 hrs/yr for 70-m antennas valued at $3M/yr.

Improvement of interplanetary frame tie will reduce navigation costs and fuel margins, and increase science return.

A key goal within this work area is the continued ransfer of new GPS technologies to private and government sectors. This shows critical contributions from NASA to technologies and issues of societal importance.

PRODUCTS:
Fully autonomous, in situ nav systems for planetary missions; autonomous formation flyer (AFF) sensor; rendezvous navigation system design using AFF; low-power new space GPS receivers for autonomous spacecraft; autonomous Wide Area Differential GPS (WADGPS) navigation system for Earth orbiters; improved planetary frame tie and planetary ephemerides; Earth orientation calibrations, DSN troposphere path delays, precise DSN time transfer.

DESCRIPTION:
In this work area, we develop, refine and prototype new technologies for autonomous spacecraft tracking and navigation. This work will eventually help NASA follow through on its stated objectives to devote more resources to science and less to routine operational tasks. Spacecraft navigation is one area which can be considerably automated. A longer term vision is to eventually enable automated onboard precise orbit determination services, to support onboard automated generation of precise science data products. These objectives will be pursued both for Earth orbiter and for deep space missions. The technologies for these two areas of application have some similarities and some distinct differences. We will maximally exploit the similarities to leverage technology development dollars. The approach is to provide different tracking capabilities as a series of services, in line with the TMOD programmatic objectives. The technical breadth of the work area has an end to end focus including: hardware development for data acquisition; algorithms for automated data processing; positioning and orbit determination estimation software; and production of refined navigation and science data

products. A recurrent theme within the work area is that tracking and navigation can be provided to end users through a system which emphasizes multi-mission capability with nearly complete automation. Current work area tasks include:

Mars Navigation with GDN — to support development of an automated in situ navigation capability at Mars;

Autonomous Formation Flyer (AFF) — to support development of a new GDN sensor;

GPS Navigation Receiver for Fully Autonomous Spacecraft — to develop a smart GPS receiver capable of autonomously controlling a spacecraft;

SNOE microGPS — development of an ultra-low-power GPS space receiver;

Global WADGPS — system analysis and design for an automated and precise Earth orbiter tracking and navigation capability;

Same-Beam Interferometry and Galileo VLBI — demonstrate and refine precision techniques for trajectory determination and navigation at other planets.

DELIVERABLES:

Develop family of low-cost GPS-derivative navigation system designs for Mars.

Develop and refine AFF design and software to meet needs of New Millennium, Mars, and space interferometry missions.

Team with new industry partner for GPS-On-A-Chip navigation receiver to enable onboard navigation and control for a fully autonomous spacecraft

Perform post-launch SNOE microGPS analysis and support flight instrument.

Deliver STRV microGPS flight receiver.

Develop detailed error budget for global real-time WADGPS navigation and complete SAR demo started in FY97; develop plan for X-33 and other demos

Complete acquisition, analysis, and delivery of Galileo VLBI data; acquire and analyze Same-Beam Interferometry measurements of Mars Pathfinder and Mars Global Surveyor

RESOURCE REQUIREMENTS BY WORK UNIT:

	JPL Account #	FY98	FY99	FY00	FY01	FY02	FY03
GPS-Like Tracking	***412-41506***	150	150	160	160	160	200
GPS Flight Systems	***412-41507***	90	110	120	130	140	150
GPS Nav Rec Auto	***412-41508***	90	90	70	58		
Same-Beam VLBI	***412-41509***	85	85	75	75	50	50
AFF Sys Dev	***586-NC019***	95	175	168	170	266	216
MicroGPS SNOE	***462-42266***	90					
MicroGPS STRV-1C	***462-42267***	10					
MicroGPS STRVUSAF	***470-42267***	121					
Total -- match WAD		731	610	593	593	616	616
Total Workforce		4.8	4.3	3.4	3.4	4.2	4.2

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: **GPS-Derivative Navigation (GDN) Technology Development for Far-Earth/Deep Space: Mars Navigation**	
WORK UNIT IN WHICH FUNDED: GPS-Like Tracking, 412-41506-0-3350	
WORK AREA: Radio Metric Tracking	

BRIEF TECHNICAL SUMMARY:

Perform system analysis and develop a family of low-cost, high-performance system designs for navigation at, on and near Mars using GPS-derivative navigation (GDN) technologies. We propose to examine the accuracies and capabilities an RF-based GDN system which exploits a high degree of leveraging from ongoing technology development for GPS-like tracking systems and for the Autonomous Formation Flyer (AFF) sensor. We intend to build on the highly flexible GPS-On-A-Chip space receiver currently being developed at JPL, whose versatile programmable ASICs enable modification of that receiver for two-way radio metric tracking and communication links, far from Earth where no GPS satellites can be viewed or tracked. The on-a-chip instrument from which the GDN sensor is to be designed also includes a powerful PowerPC processor capable of handling significant computation loads. In such a transceiver mode with multiple space vehicles, autonomous relative positioning with little or no Earth-based ground support is possible. This work should be widely applicable to other planetary missions in addition to those at Mars.

JUSTIFICATION AND BENEFITS:

The overall goal is development of a new autonomous navigation system capable of lowering operational costs, enabling new missions and navigation capabilities, providing significant new scientific measurements at low cost, and significantly improving performance and accuracy. Mars missions are specifically targeted, but the technology will be widely applicable to other non-Mars interplanetary missions. The system could support orbiters, landers, ground rovers, ground sites, ascent vehicles, and rendezvous and docking scenarios — essentially an end-to-end navigation, autonomous, multi-mission capability, all from one base highly configurable hardware architecture. The use of a common base hardware architecture emphasizes multi-mission use and minimizes non-recurring engineering costs. The cost-saving aspects of multi-mission use would be realized from an architecture with wide applicability for use in many different interplanetary missions.

NASA has planned a progression of aggressive and exciting missions in the coming two decades to visit and explore Mars. This Mars mission set has received new impetus from recent findings of potential life on Mars, as well as from the spectacularly successful Pathfinder mission. A manned mission is targeted for the 2015 timeframe. Accurate and reliable navigation is important to the success of these missions. Because of the growing number of missions requiring simultaneous DSN support, the light travel time, and the cost of DSN ground tracking services (thousands of $ per antenna hour), NASA desires and needs an autonomous navigation system which is low-cost, can be easily configured to different situations and environments, and can provide real-time navigation services for a sequence of multiple missions to Mars. For an eventual manned mission to Mars, safety considerations make such a system essential. Our goal for Mars is to enable accurate and real-time positioning in a Mars-fixed reference frame, or in a reference frame defined by other space vehicles orbiting the planet. Real-time accuracies could be provided at the 1-cm level if desired; other system configurations could provide coarser accuracies (1-meter or larger resolution). The GDN transceiver-based navigation system can also provide relative attitude determination in real-time in addition to positioning for multiple users and vehicles. At Mars, the system could support orbiters, landers, ground rovers, ground beacons, ascent vehicles, and rendezvous and docking scenarios. Compared to current-day capabilities, GDN is a quantum leap, representing a very different concept of operations. For instance, knowledge of Pathfinder's location on Mars is only approximately known, and that knowledge was obtained after-the-fact. The new GDN system could support sub-meter (and possibly cm-level) real-time position knowledge on the Martian surface, and could not only support orbiter and lander navigation, but could also support rover navigation.

APPROACH AND PLAN:

The first task will be to identify and categorize specific Mars missions and mission classes according to their navigation requirements. Then, perform system analyses and studies to characterize the following design parameters for a GDN system for Mars and their effect on performance and cost:

- number of orbiters
- number of ground sites (if any)
- data types (pseudorange, phase, Doppler)
- transmitter/receiver configurations (users, orbiters, ground sites; with and without attitude estimation)
- performance in real-time, after-the-fact
- communications link performance using GDN: bandwidth and cost for providing communications links with telemetry between vehicles
- integration of data from other sensors (star imagers, accelerometers, laser gyros,...) into the GPS-on-a-chip instrument

Our approach is to quantify system capabilities for a range of GDN hardware configurations. A key element of the plan is to regularly exchange information with Mars mission and New Millennium organizations to keep the work in this work area focused on the needs of the end users. To this end, we have already begun a dialogue with M. Adler, S. Weinstein, C. Kyriacou, K. Scott, who are all involved in Mars mission planning and system design, including Mars Ascent Avionics, and have begun providing them with technical information about GDN and the GPS-On-A-Chip hardware which could be adapted for GDN. After obtaining feedback from the future users, in a future year we plan to follow up with detailed hardware design for adaptation of GPS-On-A-Chip for GDN. After that, there will be opportunities for prototype development and terrestrial field tests and experiments. At the earliest opportunity, we will be ready to leverage from TMOT development program support to direct mission support.

The following are key elements in our approach and plan:

- Incorporate the possibility of incrementally building up a Mars GDN system using spacecraft put into Mars orbit one at a time in the upcoming sequence of Mars missions. In other words, if each of multiple Mars spacecraft in the Mars mission sequence is to be equipped with a GDN transceiver, we will be building up little by little what will become a GDN constellation at Mars. The incremental cost for each mission will be small, and this approach may be more practical then initiating a single, large, GDN initiative. The greater the number of simultaneous orbiters participating in the GDN system, the more powerful and useful the new navigation system will be.
- The interplay of information from ground (Mars) sites with “on-a-chip” GDN beacons or transceivers, with information available from conventional Earth-based tracking is an important aspect of the proposed analysis. Occasional Earth-based tracking may be needed to determine an inertial frame tie, as the GDN system by itself provides relative positioning and navigation within the Mars reference frame. Also to be investigated is the coordination with optical data which may be acquired. Part of the system design study will investigate the processing of star tracker data (or other sensor data) inside the GDN computer to enhance the trajectory and/or attitude solutions.
- Mars space vehicles are often tightly constrained by mass limitations. We will provide a family of GDN sensor configurations which encompass a wide range of performances, showing how performance depends on mass, power, and cost.
- Communications and telemetry at the 1 Mbit/s or higher can be supported by the GDN flight instrument. This will be studied and design/cost trades will be presented.
- A key element of the system is the coordination and calibration of timing and time transfer between space vehicles and the DSN. We have submitted a separate task (GDN: Mars Time Transfer) in an accompanying proposal to specifically address time transfer.
- A key feature of the GDN system is that it enables several very powerful and new radio science measurements at Mars for atmospheric and geodetic physics. We have submitted a separate task (New Radio Science Opportunities from GPS-Derivative Navigation [GDN] Technology) in an accompanying proposal to evaluate these science opportunities.
- Two other closely related proposals have been submitted. GDN: Formation Flying, and GDN: Sample, Rendezvous, and Docking Applications. Both of these proposals specifically address precision proximity operations for the GDN sensor and the Autonomous Formation Flyer (AFF) sensor.

The GDN system is a new proposal, but already is of great interest to the interplanetary community at large. The following missions, as indicated through a dialogue with the Mars Ascent Avionics team, would be GDN candidates:

2001 Orbiter	2001 Lander
2003 Mars Orbiter	2003 Mars Lander

2004 Mars Sample Return
2005 Mars Sample Return
2006 Mars Rover
2007 Mars Orbiter
2007 Mars Sample Return
2009 Mars Sample Return
2011 Cargo Ship Mission

The 2003 mission set has special interest since this set may be carried out by the Europeans. S. Lichten (33), along with R. Preston (33), W. Folkner (33), and Ryne (31) have been participating in a dialogue with Jacques Blamont, former director of the French space agency (CNES), who is now actively promoting a new Arianne V piggyback launch capability through which multiple small spacecraft could be sent to Mars or to the Moon, at very low cost (as low as $1M per launch). Blamont has asked that the GDN technology be presented to a joint NASA-CNES working group which is in the process of being established through a high level NASA-CNES agreement, to be executed at W. Huntress's level. Blamont, who is still representing CNES, has expressed a great deal of interest in the use of the AFF sensor, adapted to provide the GDN at Mars. This collaboration would be supported, in addition, by the following companion proposals:

GDN: Sample, Rendezvous, and Docking Applications
GDN: Mars Time Transfer
GDN: Autonomous Formation Flyer (AFF)

DELIVERABLES

- FY98: A series of technical reports to be delivered in the second half of FY98 describing results of orbit and trajectory analysis and simulations for Mars navigation for a range of architectures and configurations for different numbers of orbiters, ground sites (if any), datatypes, and comm-link/telemetry capability. In August 1998, these will be merged into one, or possibly two TDA Reports. Participation in the NASA-CNES working group for Mars exploration will be supported, and will ensure that collaborative efforts between the two space agencies be exploited, especially where significant cost savings could result.

- FY99 planned deliverables: develop a system design for a prototype GDN instrument. Closely link the direction of the work with specific Mars missions based on continuing interaction with the Mars mission program offices.

- FY00 plans: develop prototype GDN navigation sensor and begin ground-based measurements.

During this time period, if direct project funding becomes available, the above deliverables and schedule may be modified, as technology and infusion transfer takes place. First space flight units could be developed by the 2001 timeframe (however see comments below under Resource Requirements with regard to accelerating this schedule.)

RESOURCE REQUIREMENTS

Co-funding is not in hand at this time, but may be available if the DS-3 mission with the AFF option receives a new start in the next year. If the AFF is funded, our GDN prototyping activity, planned to begin in FY00, will be substantially accelerated and infusion could be greatly expedited. In addition to DS-3, we are coordinating with DS-4, Mars Ascent Avionics, and other related Mars (including CNES and the European consortium) and New Millennium mission planning or development activity, any of which could result in a substantial infusion and acceleration of the prototyping schedule.

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)	20	150	155	250	575
Workforce (WY)	0.1	1	1	1.2	3.3
Co-funding ($K)					0
Projected Savings ($K)					0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Global WADGPS Technology Development	
WORK UNIT IN WHICH FUNDED: GPS Flight Systems, 412-41507-0-3350	
WORK AREA: Radio Metric Tracking	

BRIEF TECHNICAL SUMMARY *(Objectives and Approach)*

This initiative develops and prototypes a global Wide Area Differential GPS (WADGPS) capability for fully autonomous precise real-time positioning of Earth orbiters and other vehicles. The system is based on the Global Positioning System (GPS), leveraging from JPL's current role in the FAA's Wide Area Augmentation System (WAAS). The global WADGPS system envisioned here will result in three significant new capabilities, each of which will result in major cost savings to the government and to the private sector: (1) Real-time 50-cm accuracy for virtually any low-Earth orbiter with a WADGPS-capable receiver; (2) Real-time orbit determination for certain low-Earth orbiters to better than 10 cm; (3) capability for real-time onboard generation of precision science data products for certain NASA remote sensing missions.

WAAS will provide precision positioning and support navigation for airliners in United States airspace starting in 1999. JPL is developing the real-time software for computing the GPS positioning and atmospheric corrections needed for the FAA system. JPL's real-time GPS software was developed from a global perspective, so it has the potential to provide full global precision navigation from GPS. Since WAAS provides coverage only over the United States, precise and validated real-time GPS corrections would not be available from WAAS for Earth orbiters except when passing over the U.S. We propose here to development of a prototype global WADGPS system to demonstrate full global coverage and fully autonomous precise positioning of Earth orbiters. Real-time orbit accuracies would be in the 50-cm range for most users in almost any low-Earth orbit, with a goal of better than 10 cm for certain user satellites under certain conditions where high accuracy is required. The use of such autonomous onboard positioning systems would enable substantial cost reductions in what are currently expensive ground operations activities. It would be an extremely valuable service which would be embraced by a very broad community including NASA, the commercial sector, other government agencies, and the international navigation community. Present-day WADGPS partnerships between JPL and a number of small and large high-technology companies have already demonstrated the high level of interest in participation in such efforts by the private sector and have highlighted JPL's success in transferring technology through mutually beneficial teaming. In addition, the global WADGPS system envisioned from this NASA development activity will provide far-reaching benefits to other government agencies and provide a capability that will profoundly affect navigation in both the U.S. and global communities.

JUSTIFICATION AND BENEFITS

The program proposed here would have significant benefits to NASA and to society in general. Ultimately, Earth orbiters carrying a WADGPS-capable GPS flight receiver would require little or no ground operations not only for routine navigation, but also for specialized high-precision positioning needs. The savings could easily amount to between hundreds of thousands of dollars to millions of dollars per year, per mission, and certainly these savings will be multiplied by a large multi-mission factor since the NASA WADGPS system envisioned here could support a completely unlimited number of users simultaneously, the ultimate in multi-mission service, since each user's passive flight instrument requires no action from the WADGPS system itself. Three main classes of users are envisioned:

• Routine navigation users. Most NASA (and non-NASA) missions require position knowledge in real-time only to the level of tens to hundreds of meters. The WADGPS system would easily surpass these requirements and would enable fully autonomous navigation systems, with onboard decision and control. Savings per year: $100K to $1M+ per mission.

• Specialized navigation users. This class of users includes missions with special needs, such as satellites which are required to follow narrowly specified ground tracks, repeat tracks, or orbits. Although the positioning accuracies in these cases generally do not require better than 1-m knowledge, they do — for instance in the case of repeat ground tracks — require special planning and calculations in conjunction with real-time knowledge of the orbit and its propagation. The development of navigation systems to meet these requirements can be very costly. Considerable effort is being expended at present to develop a scenario for meeting the repeat ground track requirements for the LightSAR mission. The Topex/Poseidon mission also requires a significant ground operations team to plan maneuvers for its repeat track; the upcoming Jason-1 and Jason-2 missions would have similar requirements. Many commercial missions fall into either this class of users or the previous one, including projects from the following companies (all of whom have either contacted JPL recently, or are under contract to JPL for GPS technology): Lockheed-Martin, OSC, TRW, Marta Marconi.

• High-accuracy science users. Earth orbiter missions in the class of Topex/Poseidon, Geosat-Follow-On, SRTM, Jason-1, Jason-2, GRACE, GLAS, and LightSAR, VCL and numerous atmosphere occultation missions (examples of missions in this class are SUNSAT, Orsted, SAC-C, Champ, the NPOES constellation) would all benefit from accurate orbit determination in real-time or near real-time. These missions are unique in the sense that very accurate (< 1 meter) orbits are required to intrinsically process the science data. Currently, all the GPS tracking data as well as the science sensor data are telemetered to the ground, where complex ground operations system must sort and organize it, and send it to various processing centers. The products of those processes are then sent to scientists. There can be a time delay of days to weeks for these processes. With the new generation of GPS space receivers in the GPS-On-A-Chip family, the embedded PowerPC processor has the power to perform significant calculation onboard in real-time, as well as handle tasks associated with real-time navigation and control decision. Such operational concepts should be a part of the navigation services provided by organizations such as TMOD. They will be essential for NASA to do more with less, and dedicate a greater percentage of its resources to science rather than mission operations. For a rather special class of high-precision ocean altimetry missions (see list with Topex/Poseidon above), the NASA WADGPS system can dramatically change the way that NASA science products are generated, leading to large reductions in cost of science operations. In the spirit of the New Millennium Program, we propose to investigate the potential to generate onboard, in real-time, further refined science data products, such as Interim Geophysical Data Records (IGDRs). Not only would this capability dramatically lower ground processing operational costs for NASA, NOAA, and the U.S. Navy (all of which invest significantly in efforts to rapidly process orbital data and assimilate it after-the-fact with science sensor data), but it would greatly enhance rapidly growing fields such as operational oceanography where interpretation of science data from low-Earth orbiters is required within a day or less in order to utilize the time-critical information for ocean science, agriculture, fishing, ship navigation, and natural hazards. The sub-10 cm onboard autonomous positioning capability could, for future missions similar to Topex/Poseidon, enable significant reductions in precise orbit determination activity. Such ground-based operational activity currently requires several million dollars per year for Topex/Poseidon. Savings per year: $100K to $1M+ per mission.

Because the WADGPS system proposed here provides a high degree of <u>reliability</u> and <u>safety</u>, in addition to high <u>accuracy</u> (for those users who need it), an enhanced version would be suitable for vehicles such as the Shuttle, X-33, and RLV (Shuttle follow-on vehicle). The WADGPS system could have a very large impact where automated maneuver calculation, decision, and control are desired for low-cost, autonomous operation. A sub-50 cm real-time global positioning capability is also currently of great interest to the NASA and DOD SAR (synthetic aperture radar) communities, substantially improving accuracy over current, more costly data acquisition and processing systems, improving the capability for immediate response to natural hazards or disasters.

APPROACH AND PLAN

In FY97, we began planning in earnest for a flight experiment onboard the NASA SAR DC-8 plane, originally scheduled for October 1998. We procured flight GPS receivers and portable computers and developed real-time software to carry out a real-time onboard positioning demo. This flight demo is seen as an important first step in bridging from our existing real-time ground positioning capability (better than 50 cm) to an eventual capability for positioning in space. The NASA plane encountered unexpected damage during a storm and is currently being repaired. We are still planning to conduct the flight experiment in FY98, but the exact time this may occur is at present unknown. Approximately 50% of the requested funding is earmarked for the one (or more) airplane flight demos which may occur in FY98. We are making alternate plans with other airplane GPS experiments we are aware of in case the NASA plane is unavailable in the next fiscal year. These alternate experiments may involve other SAR plane flights, or a geodesy GPS flight experiment in conjunction with UC San Diego. In any case, we are now ready to perform the airplane experiment as a first approximation to eventual space flight demos.

The other portion of the requested funding will be used to design the architecture and perform system analysis for the future global WADGPS system. This will include planning for future experiments with Earth orbiters; for example, the LEOT system could be used to uplink real-time WADGPS corrections to an orbiter with a GPS space receiver, provided that appropriate software could be uploaded to the satellite so that the WADGPS positioning could be performed. We are also working with the X-33 and RLV projects who are interested in the precision WADGPS system we have proposed. From X-33, we have a small amount of co-funding (0.2 wy for FY98) to participate in planning for that application. The proposal leverages heavily off existing tasks funded by the FAA, ongoing JPL partnerships with at least two companies in WADGPS, and several NASA- and DOD-funded tasks. By FY99, JPL's real-time GPS software will have been fully transferred to Hughes for use in the operational FAA WAAS system over the United States. SATLOC, a smaller agriculturally oriented GPS company, has commercialized JPL's system in the United States and has already begun broadcasting JPL GPS corrections to users through geosynchronous satellites.

The effort will be broken into the following sub-tasks:

1) Develop a detailed error budget for JPL's mechanization of an optimally implemented global WADGPS system.

2) Develop an experiment plan for operating a global real-time WADGPS system for a limited amount of time to obtain empirical measures of performance, which may require special efforts to acquire real-time data globally.

3) Operate the experimental global WADGPS system for a limited time (preferably at least several weeks) and test performance with user positioning on the ground, in the air, and in space. JPL already operates a large portion of a sophisticated global GPS network and generates global GPS products with latencies of ~ hrs to days for various different customers. This sub-task will leverage maximally off current and ongoing tasks funded by the FAA, by the DOD, and by NASA, and will utilize the existing global network, a significant portion of which is operated by JPL.

4) Make enhancements or improvements to the prototype global WADGPS system based on lessons learned from the experimental operation, including a sub-10 cm accuracy capability for real-time low-Earth orbiter positioning.

5) Develop a long-range plan for a continuously operating global WADGPS system for NASA to start in FY02.

6) Perform airplane flight demo(s) in FY98.

DELIVERABLES (see tasks listed above)
• Task 1 (FY98): technical report, 8/98.
• Task 2 (FY98,99): written experiment plan, with costs and schedule, for experimental global WADGPS tests.
This task originally planned for 12/99, may be deferred due to reduced FY98 funding awarded ($90K, versus 135K)
• Task 3 (FY99-00): analysis of global WADGPS data, and written report. 12/00
• Task 4 (FY99-00): new sub-10 cm s/w, algorithms, with field tests. Reports documenting algorithms and tests. 9/00
• Task 5 (FY00-01): plan with schedules and costs for NASA global WADGPS implementation and operation. 6/01
• Task 6 (FY98): complete experiment and report results in TDA Report. *Completion of this task may be deferred until FY99 (originally planned for 9/98) due to reduced FY98 funding awarded ($90K, versus 135K)*

RESOURCE REQUIREMENTS

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)	90	90	200	275	655
Workforce (WY)	0.3	0.8	1.2	1.5	3.8
Co-funding ($K)	510	140			650
Projected Savings ($K)					see note

Co-funding is from FAA (FY97, FY98) and JPL X-33 (0.2 wy in FY98) projects. Projected savings is $1M-$5M per year starting in FY02, if the global WADGPS system were to begin operations in FY02.

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: GPS Navigation Receiver for Fully Autonomous Spacecraft	
WORK UNIT IN WHICH FUNDED: GPS Nav Receiver for Fully Autonomous Spacecraft, 412-41508-0-3350	
WORK AREA: Radio Metric Tracking	

BRIEF TECHNICAL SUMMARY *(Objectives and Approach)*

Development of the world's first CA-only navigation GPS receiver for controlling a fully autonomous spacecraft. The goal is to save operations costs with a GPS navigation receiver for satellites which incorporates fully autonomous maneuver planning and execution software. This task is the follow-up on the “1/100/100 receiver” task which has received several workmonths funding for the past two years in the TMO Technology Program. In the proposed task, we will provide a design, demo components, integrate into the GPS-On-A-Chip (GOAC) development, and produce a prototype in FY99.

JUSTIFICATION AND BENEFITS

This task leads to a fully integrated, small, low-mass, low-power, credit-card sized flight GPS unit which, when flown on a satellite, can autonomously navigate the spacecraft. This approach would eliminate ground operations costs for many Earth orbiter missions for navigation and stationkeeping. This cost-savings could result in hundred of $K per year per mission; as each new mission is launched, additional savings are realized. Virtually every Earth orbiter mission in the year 2000 and beyond would be a potential user.

APPROACH AND PLAN

This task leverages strongly on the GPS-On-A-Chip (GOAC) effort, currently funded through TAP. It adds to that compact, high-performance receiver some important functionality, specifically maneuver decision and functionality. This is the remaining component needed for full autonomy for Earth orbiters. Section 335 will provide the oversight of the task, as the technical lead on the GOAC receiver. The plan is to have a commercial partner provide the real-time embedded software for the onboard real-time maneuver decision and control. At least two such potential partners have been identified at present; due to the current RFP which has been issued for GOAC, however, specific company names cannot be provided right now. Based on the needs of the integration effort, it may also be desirable to incorporate some contribution from divisions 31 and 34.

DELIVERABLES

• FY 98 -- produce a system design plus modules for (a) maneuver decision, and (b) maneuver execution, to eventually be part of a GOAC flight GPS receiver for an autonomous satellite. Bring the commercial partner into the task through a contract.
• FY 99 -- integrate the new modules into a GOAC prototype and test using JPL's GPS orbit simulator. We will run constellation scenarios on our simulator which will stimulate our receiver-under-test to plan and execute maneuvers. Outputs will be the commands to the satellite attitude control devices and thrusters, which will be compared with the known requirements for maneuvers.

RESOURCE REQUIREMENTS

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)		90	120		210
Workforce (WY)		0.6	0.7		1.3
Co-funding ($K)	50	150	175		375
Projected Savings ($K)					0

Note: a portion of the workforce will be that of a TBD contractor (commercial partner). For projected savings, after the year 2000, we anticipate that this receiver could save more than $1M/yr if 4-5 orbiters per year carry it onboard for autonomous operation. Per unit costs are anticipated to be less than $100K each.

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: **Same-beam VLBI Observations of MGS and Pathfinder**	
WORK UNIT IN WHICH FUNDED: Same-beam VLBI Observations of MGS and Pathfinder, 412-41509-0-3350	
WORK AREA: Radio Metric Tracking	

BRIEF TECHNICAL SUMMARY *(Objectives and Approach)*

The objective is to demonstrate improved spacecraft position determination by simultaneously tracking, at two DSN sites, the carrier signals of two spacecraft in the same antenna beam. When Mars Global Surveyor reaches Mars in September 1997 it can be simultaneously tracked with Mars Pathfinder. We propose to support a series of experimental tracking passes and to process and analyze the data to demonstrate improved position determination for Pathfinder and MGS.

JUSTIFICATION AND BENEFITS

When multiple spacecraft are simultaneously visible in the beam of a single antenna, they can be simultaneously tracked by an appropriate receiver. This reduces some common error source for the radio metric observables, allowing for improved orbit determination, and for reduced usage of DSN resources. This was demonstrated earlier with Magellan and Pioneer 12 in orbit about Venus. The earlier experiments showed order-of-magnitude improvements in orbit determinations, from about 1 km orbit position uncertainty to about 100 m (1 sigma). The MGN-PVO demonstration was performed at S-band. Covariance analysis done at the time indicated that with two spacecraft at Mars at X-band the orbit determination should be improved from about 200 m for the low orbiter (MGS) to about 10 m (1 sigma). This improved orbit determination, if achieved, can lead to improved science results from the registration of measurements. An example of this is that altimeter measurements can be made at the same point at different times to investigate changes, e.g. in the ice cap thickness at the poles. This requires orbit determination better than the footprint of the altimeter (50 m for MGS). If the tracking is with respect to a lander such as Pathfinder, the lander position should be determined to better than 10 m in a single tracking pass. For Pathfinder this can lead to a more rapid determination of Mars precession than would otherwise be achieved. The technique might also be useful for future Mars rover missions, enabling determination of their positions to a few meters in single tracking passes.

This work has been endorsed by the MGS radio science team led by Len Tyler, and by the Mars Pathfinder Rotation Dynamics experiment, led by Bill Folkner.

APPROACH AND PLAN

MGS enters orbit about Mars in September 1997. For about 3 weeks in September and October the DSN schedule includes tracking time for either MGS or Pathfinder at Goldstone at the same time that tracking for the other spacecraft is scheduled at Canberra. The signals from both spacecraft can be simultaneously recorded at each site using the Experimental Tone Tracker (ETT). We will acquire as much data as possible. The ETT data will be processed and used to solve for the positions of Pathfinder and MGS. The positions from consecutive tracking passes will be compared to evaluate the accuracy of the tracking. After October the project science teams are interested in perhaps weekly experiments. If the DSN time is scheduled by the project, the ETT will continue to be used to acquire data, which will be delivered to the project radio science teams for analysis.

DELIVERABLES

Simultaneous spacecraft observables will be delivered to the project radio science teams after acquisition by the ETT. A report on the results of the tracking experiments will be documented in a TDA Progress report at the end of FY ‘98.

RESOURCE REQUIREMENTS

These tracking experiments are dependent on the health of Pathfinder and MGS in September and October, on the DSN tracking time allocations, and on Pathfinder transmission scheduling. So far both projects have informally agreed to participate in the experiments.

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)		85			85
Workforce (WY)		0.6			0.6
Co-funding ($K)					0
Projected Savings ($K)					0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: **Autonomous Formation Flying Technology Development**	
WORK UNIT IN WHICH FUNDED: Autonomous Formation Flying Technology Development, 586-NC019-0-3350	
WORK AREA: Radio Metric Tracking	

BRIEF TECHNICAL SUMMARY *(Objectives and Approach)*

Develop the basic technology and system design for an autonomous formation flyer (AFF) flight instrument to enable two or more spacecraft, in interplanetary space or in trajectories near a planetary body, to autonomously measure precise relative position and attitude and maintain a precise relative formation or configuration. Under normal operating conditions, the AFF autonomously controls the configuration or formation of multiple space vehicles without need for input from ground or Earth. The AFF incorporates dual one-way radio metric tracking links with high-accuracy capability, a powerful onboard PowerPC processor and a communications link so that data and spacecraft commands can be exchanged in real-time. Define the hardware architecture, with clear-cut development path from conceptual design to prototype to first flight test. Specify the anticipated cost, schedule, and development plan for the first AFF flight instrument. Develop conceptual design for autonomous formation and/or constellation controls for multiple spacecraft systems. Develop and test algorithms and prototype code for embedded real-time software to compute relative position and attitude for two or more spacecraft in a formation or constellation. Perform simulations to analyze performance of different embodiments of the AFF, and develop system error budgets for AFF configurations corresponding to missions under development or consideration by NASA/JPL. This task will lead to proof of concept for the AFF and enable rapid infusion to mission-specific flight unit development.

Note: this is the second year of a two-year CIP task which was initially funded in FY97.

JUSTIFICATION AND BENEFITS

AFF technology development has significant multimission benefits and impact in two primary areas:

(1) AFF technology is needed for multiple spacecraft to maintain precisely defined formations, as are typically required for space interferometric missions, while requiring little or no ground tracking operations. This is an enabling technology for a whole new class of deep space NASA missions to pursue aggressive scientific goals (such as searching for planets at other stars) at very low cost. It emphasizes the philosophy of the New Millennium Program, focusing on making space exploration missions autonomous and having the spacecraft make measurements and intelligent decisions onboard to autonomously self-navigate. Examples of currently planned missions where this technology is required include interferometers such as DS-3 (Separated Spacecraft Interferometer); others would include future missions modeled after ALFA (Astronomical Low Frequency Array), ExNPS (Exploration of Neighboring Planetary Systems), and MUSIC (Multiple Spacecraft Interferometer Constellation). There is also an entire class of Earth-orbiter missions which could utilize AFF technology, including missions modeled after TOPSAT, GRACE, EO-1, EMM (Earth Mapping Mission), SAGITTARIUS, ATMS and others where spacecraft-spacecraft direct measurements and communication are needed in Earth orbit.

(2) Rendezvous and docking at or near planets or planetary bodies require an autonomous sensor which can from arbitrary initial orientations, search for, locate, track, and rendezvous with or intercept other space vehicles. Examples of such missions include: DS-4, Champollion, comet rendezvous and sample return (CRSR) and other variants on DS-4, Mars Ascent Vehicle and Mars Sample Return, and several proposed low-cost lunar missions. A common theme in several of these scenarios is an orbiter plus a lander; options include multiple lander beacons or sample return to the orbiter.

A key factor in many of the applications in both of these categories is the practical reality of needing to provide for autonomous constellation or formation control. This presents a new concept of operations. The combination of low mission operations budgets, light travel time to Earth, simultaneous multiple other ongoing missions, and New Millennium-style autonomy means that routine maneuvers for spacecraft trajectory or formation control (which may occur on timescales of seconds for missions such as DS-3) must be computed, communicated, and initiated remotely through an autonomous onboard system. The AFF provides the key components and functionality of this system.

APPROACH AND PLAN

The system design began in FY97 with joint support from CIP ($75K) and TMO Technology ($20K) programs. Initially, we conducted a study of technologies available for self-tracking systems at radio frequencies. A preferred system had been prototyped in section 335 for time transfer using commercial GPS receivers in the mid-1990s. The receivers can be modified to broadcast as well as receive, and hence can self-track one another in Earth orbit or in deep space. The new GPS-On-A-Chip receiver under development by section 335 was identified as the best available technology path for the future AFF. The AFF will be a new RF-based transceiver built from the GPS-On-A-Chip receiver, exploiting the resources already committed for developing that particular GPS receiver, which has a highly versatile and flexible architecture.

The approach is to develop an initial system design for the hardware, consisting of modified GPS receivers which can transmit and receive special ranging signals (non-GPS). The two-way time transfer system developed in section 335 under the TMO Technology Program in the mid-1990s showed potential for sub-cm ranging. Such accuracies are needed for some missions, such as the New Millennium Separated Spacecraft Interferometer (DS-3). In FY97, block diagrams and a conceptual design was developed for the AFF. These were provided to Mars Ascent Avionics teams and to DS-3. In addition, several briefings were provided upon request by DS-4 planning teams. Our approach has, and will continue to be, one of constant communication with developing NASA missions to ensure that the AFF meets their requirements. We also participated on the DS-3 formation flying special planning team in FY97, and provided a complete cost estimate and schedule for development and production of flight units for the DS-3 mission. While continuing to evolve in accordance with mission needs as transmitted to us, the .base hardware architecture for the AFF has now been specified. Certain design features must still be evaluated; for example, the frequency (RF) for the AFF could be L-band, S-band, X-band, or K-band (or some other frequency). The power consumption of the AFF may hinge on the choice of frequency, and appropriate trades may have to be made with mass and other characteristics which will be different for different frequencies. For the Mars Ascent Vehicle (and other ascent spacecraft), it is likely that the preferred embodiment will be that which has the minimum mass. Detailed mass and power estimates were provided to the Mars Ascent Avionics planning team in FY97 upon request. The exact number of receive antennas may also depend on whether directional or omni antennas are used; this in turn may hinge on multipath reduction requirements.

The software development work began in FY97 and focused on relative positioning in real-time. Initially, a system analysis was performed to characterize the number of measurements and estimated states and their observability from an AFF configuration appropriate for a three-spacecraft separated spacecraft interferometer modeled on DS-3. A real-time formation flying simulator software suite was developed for testing. This software, developed as prototype real-time AFF flight software; utilizes an extended Kalman filter, selected models from RTG (Real-Time GIPSY), and includes attitude estimation processes. Noise-free simulations produced exactly correct answers, confirming that that the basic algorithms had been soundly coded. Formal errors for covariance analysis with 1-cm ranging, 10μ K-band phase (purely random noise only) were 0.41 cm for inter-spacecraft distances, 0.33 cm for clock biases, and 6 – 12 microradians (< 0.1 arcmin) for attitude angles. Different AFF scenarios with realistic data noises, added process noises, multiple data epochs, and different geometries are currently being studied. Preliminary results have also been obtained for the critical cold start/initialization part of the problem; certain conditions have been identified which may lead to lack of convergence, and a new strategy is being developed to cope with that situation. DS-3 requires a capability to initialize the formation from an arbitrary and possibly tumbling starting state.

A white paper on the AFF was written in FY97 and was accepted in the New Millennium Autonomy IPDT. A presentation was made to a review board in July 1997 for the DS-3 mission. A full conceptual design was presented at that session for the AFF for DS-3, including cost and performance. Several outstanding issues for DS-3 have since been brought to our attention, including a potentially tighter attitude requirement (see below). A patent submission was prepared for the AFF and Caltech will file the final application by the end of FY97.

DELIVERABLES

For FY98, we plan to continue the analysis and design trade off assessments which were started in FY97. The following are areas which we have been asked to address for DS-3:

• DS-3 requirements: ±1 cm relative ranging, ±1 arcminute relative orientation, ±0.1 mm/sec relative velocity;
• Assessment of a tighter attitude requirement for DS-3, to possibly 30 arcsec

• Quantifying the power and mass requirements for different embodiments of the AFF, for instance for ascent vehicles versus formation flying sensors;
• Enhance the performance simulations to enable a specification on the hardware to be placed on internal instrumental biases. These biases are expected now to be the limiting errors for ranging and relative attitude, and they may vary somewhat with temperature. For instance, as the DS-3 interferometer is repointed to different sources in inertial space, solar heating will vary.
• Develop modified AFF designs to accommodate different mission needs, such as the minimalist desired configuration for the Mars Ascent Vehicle.
• Analyze the formation flying problem for an ALFA (or ALFA-like) mission, which is being considered for a MIDEX mission. ALFA is a low-frequency space VLBI constellation of 16 or more spacecraft, requiring meter-level relative positioning. The challenge is to devise a technique requiring very low power for the AFF.
• Coordinate instrument studies in this task with constellation and formation analysis carried out in other parts of the work area. It is important to maintain continuity between the system analysis and functionality studies, and the instrument design and performance analysis.

If DS-3 receives a new start sometime in FY98, we will be poised for a significant infusion if that mission decides to include the AFF in its baseline mission plan.

RESOURCE REQUIREMENTS

Our long-term plan calls for coordination with GPS-On-A-Chip development so that a prototype AFF could be developed in FY99-00. This timetable could be accelerated with direct infusion from DS-3 sometime in FY98.

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)	95	95	190	195	575
Workforce (WY)	0.7	0.7	1.2	1.2	3.8
Co-funding ($K)	15				15
Projected Savings ($K)				see note	0

note: Without the new formation flying technology, the cost to maintain a DS-3 or ALFA type of formation from ground-based tracking would be many millions of dollars (each) and cost-prohibitive; the missions could not proceed. Also: co-funding of $15K in FY97 was from a joint DS-3 effort sponsored by TAP and the New Millennium Program.

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: **SNOE microGPS Mission Analysis and Flight Instrument Support**
WORK UNIT IN WHICH FUNDED: microGPS SNOE, 462-42266-0-3350
WORK AREA: Radio Metric Tracking

BRIEF TECHNICAL SUMMARY *(Objectives and Approach)*

Provide post-launch flight instrument support for the SNOE microGPS bit grabber GPS space receiver (BGGSR). SNOE is anticipated in November 1997. Perform post-launch analysis of GPS flight data from the SNOE microGPS BGGSR to validate proper operation and performance in its first use in space. Compute orbits for the SNOE spacecraft during periods when BGGSR data are collected to verify the hardware and to demonstrate that sub-200 meter orbit accuracy can be achieved with an ultra-low power (< 0.1 watt), low mass (< 600 grams) microGPS receiver.

JUSTIFICATION AND BENEFITS

NASA Code O funded the rapid development of the new microGPS BGGSR. The project took a success-oriented, aggressive, no-contingency approach to development of a new and unique space GPS receiver especially well-suited to a new class of small, low-power, low-mass, low-cost satellites. The BGGSR is now ready for its first space flight on the NASA SNOE mission. SNOE is a student demonstration experimental satellite designed to study the Earth's atmosphere. The SNOE spacecraft is being built by the University of Colorado. The microGPS BGGSR development was a unique teaming effort between NASA and the University of Colorado. JPL sub-contracted some key tasks to the university, and several students were supported under one contract, including one who is about to receive a Ph.D. with a dissertation about the BGGSR. The BGGSR was developed at JPL with the goal of showing that a GPS space receiver with ultra-low power and ultra-low mass could provide orbit knowledge for a small satellite at the sub-200 meter level. This level of accuracy would be sufficient to provide routine navigation support for a large number of NASA (and non-NASA) spacecraft. It opens the door to a new technology to provide very low-cost navigation support for very small and cheap satellites. As described below, JPL's microGPS software was developed to run in real-time onboard a satellite; this unique combination of hardware and software could ultimately enable a new type of fully autonomous spacecraft utilizing a flight instrument which only insignificantly impacts the mass, power, and form factor on the satellite. The reduction in navigation operations costs would be enormous as ground operations activity for routine orbit determination and navigation would eventually disappear. While other, more conventional GPS space receivers also can offer this advantage in principle, in practice the cost of flight GPS instruments remains a hurdle for many government and commercial missions. The extremely low cost of the microGPS BGGSR alleviates that drawback.

The microGPS BGGSR is comprised only of one or more GPS patch antennas, a signal sampler, a down-converter, and a memory chip. All the hardware, which includes just a few parts, fits on a small board. These parts are readily available in hardened versions from commercial sources; ultimately, the per-unit cost should be in the $10-20K range. Because of the extremely simplified hardware design, the microGPS consumes less than 1% of the power required by typical GPS receivers. On the other hand, the raw GPS data it collects require much more storage than would data from a full GPS space receiver. The raw GPS data from the BGGSR are analyzed in a unique set of software, JPL's RTG (Real-Time GIPSY) program which was developed in 1996. RTG is written in ANSI C and was written to be utilized as space flight hardware in a flight processor, or equally well in ground microcomputers. RTG currently runs on UNIX workstations, PowerPCs, and PCs (under Windows NT). The long-term vision for microGPS and RTG is that they could be used for real-time onboard orbit determination and spacecraft navigation, or with RTG running in a ground PC, for near-real time orbit determination. The latter scenario was chosen for SNOE, partly because of constraints on the spacecraft and partly to reduce costs. A second flight test of the microGPS BGGSR is planned in about 1-1/2 years on the STRV-1C mission.

NASA Code O provided original funding support for microGPS BGGSR hardware development, but no funding was included for post-launch support, receiver operation, or orbit analysis. Post-launch funding was first allocated in FY97 through the TMO Technology program in anticipation of a March 1997 launch; that launch date was repeatedly pushed back, however, due to SNOE's delayed spacecraft development (none of which had anything to do with the JPL microGPS experiment). In July 1997, the FY97 SNOE post-launch phase funding was taken back by the project office when it became clear that the launch delay would extend past the end of FY97. We must now request that a small portion of the pre-launch integration and test funding and all of the post-launch funding be provided for use in FY98.

This funding is essential because JPL has a commitment to support the microGPS instrument payload on SNOE, as well as the University of Colorado in student and faculty research which is centered on the microGPS BGGSR. Strategically, the work is critical in the first step towards the more sophisticated second version of the microGPS BGGSR, which will be flight tested in early 1999 on the U.K. STRV-1C satellite. That project is jointly supported by NASA and the DOD; the STRV-1C microGPS instrument and software will have 20 MHz sampling (up from 2 MHz for SNOE) and a dual-frequency Y-code capability. It will provide a first flight test of GPS tracking at geosynchronous altitude, answering many questions about feasibility of tracking GPS in high-altitude orbits at a small fraction of the cost of providing a conventional GPS receiver for STRV-1C. During the early part of the SNOE mission, a United Kingdom lead investigator (JPL collaborator) on the STRV-1C mission will visit JPL and while being trained to utilize the JPL microGPS software, will contribute to the analysis and data processing, at no cost to NASA or JPL.

A secondary benefit from the microGPS technology development is that the microGPS BGGSR is being adapted as a fail-safe front end for the new GPS-On-A-Chip space receiver, a revolutionary new receiver under development at JPL. The potential commercialization of the bit-grabber hardware will be explored.

APPROACH AND PLAN

• JPL will complete pre-launch integration and test with the microGPS BGGSR configured inside the SNOE spacecraft in early FY98.
• JPL will provide the necessary post-launch support the SNOE project for and operation of the microGPS BGGSR. This activity will include commanding the receiver, full checkout and verification of proper operation, software uploads as necessary, and reconfiguration of the receiver (if required). Most of the parameters of operation can be controlled remotely from the ground.
• JPL will provide software support for the microGPS software (RTG), which will be provided to the University of Colorado for use during the SNOE mission. This will also require a licensing agreement for the software between Caltech and the University of Colorado.
• We will carry out the microGPS orbit determination demonstration to verify that the system can provide the accuracies recently implied from simulations performed in FY97. Although the experiment goal is 200 meters for orbit accuracy, our simulations indicate that performance better than 100 meters might be achievable.
• We will host a visitor from the Defence Evaluation and Research Agency (DERA) of the United Kingdom who will participate in SNOE microGPS analysis and contribute to the processing of the data.

DELIVERABLES

• Integration and test of the microGPS hardware on the SNOE spacecraft. To be completed by November 15, 1997.
• Commands to operate and reconfigure the microGPS BGGSR, on an as needed basis after launch.
• Validation and checkout of proper BGGSR function, to be reported in a TDA Progress Report, a conference paper, and a refereed external paper.
• Updates to the microGPS software, continuously during FY98.
• Final version of microGPS software (RTG) to be delivered to the University of Colorado prior to launch, contingent on a signed license agreement between Caltech and the University of Colorado.
• SNOE ephemerides, determined during the periods that the BGGSR is operated on SNOE. These will be archived and exchanged with collaborators at the University of Colorado and at the U.K. DERA. A TDA Progress Report will be written, plus a conference paper and an external refereed paper on the orbit analysis.

RESOURCE REQUIREMENTS

For FY98, $70K (the amount originally allocated in FY97) in post-launch funding is requested and $20K is requested to cover the final short period of pre-launch integration and test on the spacecraft. Launch was last officially scheduled for October 7, 1997, but realistic estimates place that launch closer to the end of November.

	Prior Year(s)	FY98	FY99	FY00	Total at Completion
Funding ($K)	460	90			550
Workforce (WY)	2.5	0.7			3.2
Co-funding ($K)					0
Projected Savings ($K)					0